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Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based ceramic crowns

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Statement of problem. The influence of different crown foundations on marginal seal and fracture resistance of ceramic crowns placed on endodontically treated teeth has not been clearly established.

Purpose. The purpose of this study was to evaluate the marginal continuity and fracture behavior of high-strength all-ceramic crowns with different substructures in endodontically treated premolars.

Material and methods. Forty-eight human mandibular premolars were assigned to 6 groups including a no-treatment group (UNTREATED) and a group for which the access cavity was restored with composite resin (Tetric Ceram) (COMP). In the remaining 4 groups, teeth were prepared to receive all-ceramic crowns with 0.8-mm-wide shoulders and axial dentin heights of 2 mm. No posts were used in the ENDOCROWN group. Glass fiber posts (FRC Postec) were used in group FRC-POST. Group ZRO-POST received zirconia ceramic posts (CosmoPost), and group GOLD-POST received cast gold posts (CM). Experimental lithia disilicate ceramic crowns were made and adhesively cemented (Variolink). All teeth were subjected to thermal cycling and mechanical loading (TCML) in a masticator (1,200,000 loads, 49 N, 1.7 Hz, 3000 temperature cycles of 5°C–50°C–5°C). Marginal continuity was evaluated with scanning electron microscopy at ×200. All specimens were loaded to failure in a universal testing machine at 0.5 mm/min after TCML. Data were analyzed using 1-way ANOVA and post hoc *t* tests with Bonferroni correction (α=.05)

Results. Initially, mean values (SD) between 72.4 (15.8)% (ENDOCROWN) and 94.8 (3)% (FRC-POST) continuous margins were found. With TCML, marginal continuity decreased significantly only in FRC-POST to 75.5 (8.4)% and in ENDOCROWN to 44.7 (14.5)%. Mechanical load testing measured mean loads to failure between 1092.4 (307.8) N (FRC-POST) and 1253.7 (226.5) N (ZRO-POST) without significant differences between groups. Deep root fractures were observed in half of the specimens irrespective of their groups.

Conclusions. Marginal continuity of the crowns studied was better and more stress resistant when posts and cores were included in the restoration of endodontically treated teeth with complete ceramic crowns. The placement of a post-and-core foundation did not influence the pattern of failure.

CLINICAL IMPLICATIONS

Based on the comparison of marginal continuity values, the use of a post-and-core foundation is recommended to enhance the stress resistance of lithia disilicate-based ceramic crowns placed on endodontically treated premolars. There seems to be no material tested that would be preferred over the others for the fabrication of the ceramic crown foundations.

Although there is evidence that the loss of dental hard tissue during post space preparation reduces the rigidity of the tooth,[1] a tooth with a large loss of tooth structure generally requires a post-and-core foundation to provide restoration retention.[2] To avoid possible operational errors during post space preparation,[3] an alternative approach without use of endodontic posts, described as an endo-crown, was introduced.[4] Endo-crowns are described as crowns fabricated for endodontically treated teeth without the placement of access cavity restorations. They completely cover all cusps and extend into the access cavity to the pulpal floor level. Endodontically treated molars restored with endo-crowns have been reported to be clinically successful.[5] However, a clinical and an in vitro study indicated more frequent problems with endodontically treated premolars restored with endo-crowns.[5,6] Composite resin endo-crowns, and composite resin crowns with different types of post-and-core substructures, showed few differences regarding fracture patterns and loads to failure.[6] After thermomechanical loading in a computer-controlled device simulating mastication, composite resin endo-crowns exhibited severe marginal continuity losses, indicating a higher risk for marginal discoloration,[7] secondary caries, or restoration debonding.[8] Endodontically treated teeth restored with high flexural strength posts (gold alloy: 90 GPa and zirconia ceramic: 200 GPa) had negligible decreases in marginal continuity at the tooth-to-luting-composite resin interface.[6] Glass fiber post (30 GPa) and composite resin core (14 GPa) foundations combined with composite resin crowns with a low modulus of elasticity (14 GPa) resulted in significantly greater marginal continuity losses.[6] It was concluded that more rigid post materials had a significantly positive effect on the marginal continuity of composite resin crowns.[6]

Even though the optimal modulus of elasticity for a post has been discussed, the issue remains controversial.[9-11] Rigid posts and cores may support coronal restorations better and distribute stress more uniformly; however, if the tooth is overloaded, a catastrophic failure, such as a vertical or deep root fracture, may result.[12,13] A more elastic post may bend under high loads, resulting in loss or failure of the restoration, but would leave the root intact for retreatment.[14,15] However, an elastic post may allow the restoration to move and compromise the luting cement. Subsequent leakage would put the tooth at risk for secondary caries and/or root canal reinfection.[6,8,16] This hypothesis may be confirmed by clinical data, which indicated more secondary caries in endodontically treated premolars with fiber posts and composite resin restorations compared to amalgam restorations.[17] However, according to one literature review, no clear advantages were identified for any of the tested post materials.[18] In contrast, another literature review described advantages for glass fiber-reinforced composite resin posts.[19]

The aim of the present study was to evaluate marginal continuity, fracture modes, and loads to failure of rigid lithia disilicate-based all-ceramic crowns placed on endodontically treated premolars supported by different substructures. A computer-controlled device to simulate mastication with simultaneous thermal cycling was chosen to simulate degradation of restorative materials in the oral cavity by cyclic loading. Subsequently, specimens were loaded to failure to evaluate failure behavior. Static loads were applied in an oblique direction, which is more detrimental than an axial load.[20] Crown preparations, foundations, and loading procedures were identical to those of a previous study, except for the ceramic material used to fabricate the crowns.[6] It was hypothesized that a rigid crown material, combined with a preparation design leaving a substantial amount of residual tooth structure, would limit the bending movements of intermittently loaded crowns by reducing the influence of foundation flexure. Therefore, the first null hypothesis was that marginal continuity of all-ceramic crown restorations placed on endodontically treated premolars would not be diminished by repetitive loading. The second null hypothesis was that loads to failure would not differ between the test groups.

MATERIAL AND METHODS

From the data of a previous study,[6] a power analysis was done to determine the number of specimens that would be required in each test group to determine statistical differences between the groups. Based on this analysis, 48 mandibular premolars were selected by visual inspection, digital caliper measurements (Capa 150; Tesa SA, Renens, Switzerland), and radiographs (Digora FMX; Soredex, Helsinki, Finland) from a collection of pooled extracted teeth. Teeth were divided into 6 experimental groups (n=8). All teeth had 1 radiographically visible root canal, no cervical or root caries, and similar diameters (buccolingual: 7.3 ±0.6 mm, and mesiodistal: 4.7 ±0.3 mm) measured at the prospective finish line. Teeth with curved roots and wide or atypically shaped root canals were excluded. The teeth were stored in a 0.1-M thymol solution (Kantonsapotheke, Zürich, Switzerland) from the time of extraction until prepared for the study. The patients had given their informed consent before extraction for their teeth to be used for research purposes. The teeth were extracted in the course of a comprehensive dental treatment plan. The donors were fully and irreversibly made anonymous. The Ethics Committee of the Center for Dental and Oral Medicine and Oral and Maxillofacial Surgery of the University of Zurich supervised correct handling of the specimens. All external debris was manually cleaned from the teeth with dental scalers, nylon bristle brushes, and pumice.

The teeth for groups COMP, ENDOCROWN, FRC-POST, ZRO-POST, and GOLD-POST received root canal treatment as described previously.[6] The access cavities were closed with a provisional restorative material (Cavit; 3M ESPE, Seefeld, Germany). To ensure complete setting of the provisional material, all teeth were immersed in tap water at 37°C for 7 days.

Teeth in group UNTREATED were left untreated (Table I). In group COMP, the provisional restorative material was removed and the root filling material (Gutta Percha; Roeko GmbH, Langenau, Germany and AH Plus; Dentsply DeTrey, Konstanz, Germany) was removed to the cementoenamel junction level using a diamond rotary cutting instrument (45-µm abrasive grit, Intensiv No. 4036; Intensiv SA, Grancia, Switzerland). The enamel was selectively etched with 35% phosphoric acid (Ultra-Etch; Ultradent, South Jordan, Utah) for 30 seconds and rinsed with water spray for 40 seconds, and a dentin adhesive system (Syntac Classic; Ivoclar Vivadent, Schaan, Liechtenstein) was applied to enamel and dentin according to the manufacturer's instructions. The access cavity was filled with a fine hybrid composite resin (Tetric Ceram; Ivoclar Vivadent) in 1 horizontal and 2 oblique increments, each polymerized separately for 60 seconds (1000 mW/cm2, Optilux 500 with Turbo Tip; Kerr Corp, Orange, Calif). The restoration surface was finished with an 8-µm abrasive grit diamond rotary cutting instrument (Intensiv No. 9274) and polished (Occlubrush; Kerr-Hawe, Bioggio, Switzerland).

The clinical crowns of all teeth in groups ENDOCROWN, FRC-POST, ZRO-POST, and GOLD-POST were removed, leaving roots 13 ±1 mm in length. The roots were fixed in carriers in a dental surveyor (PFG 100; Cendres & Metaux SA, Biel, Switzerland) , and circumferential preparations with 0.5-mm-wide shoulders and 2-mm axial wall heights were made using 4-degree tapered, 80-µm abrasive grit size diamond rotary cutting instruments (Intensiv No. FG 8113NR; Intensiv SA) with water spray. With the same instrument, a 2-mm-deep central inlay type cavity was prepared with an oval antirotation shape and dentin wall thicknesses of at least 1 mm. Preparation finish lines followed original cementoenamel junctions and were located in dentin only.

In group ENDOCROWN, no posts were inserted. After primary coarse preparation, the preparations were completed and finished with 25-μm abrasive grit diamond rotary cutting instruments (Intensiv No. FG 3113NR; Intensiv SA) to the same shape and taper as the previously described specimens, resulting in preparations with 0.8-mm-wide shoulders and 2-mm axial wall heights. In group FRC-POST, size 1 (cervical diameter 1.5 mm) cylindroconical glass fiber posts (FRC Postec, lot GL0015; Ivoclar Vivadent) were placed. The post space was created by enlarging root canals to a depth of 10 mm measured from the sectioned surface of the roots using the manufacturer's recommended drill in a slow-speed contra-angle handpiece (Sirius; Micro-Mega, Besancon, France). The canals were rinsed with tap water and an adhesive system (Syntac Classic; Ivoclar Vivadent) was applied with paper points according to the manufacturer's instructions. The bonding agent (Heliobond; Ivoclar Vivadent) was applied with paper points, but not polymerized separately. The glass fiber post was shortened to a length of 15 mm with an 80-μm abrasive grit size diamond rotary cutting instrument (Intensiv No. FG 8113NR; Intensiv SA) without water cooling. Silane (Monobond-S, lot G20300; Ivoclar Vivadent) was applied on the post. After 60 seconds of air-drying time, a thin layer of adhesive (Heliobond; Ivoclar Vivadent) was applied to the post and carefully thinned with air. A dual-polymerizing resin luting material (Variolink; Ivoclar Vivadent) was mixed in a 1:1 ratio of base to catalyst. The mixture was applied to the surface of the silanated and bonding agent-coated post, which was subsequently inserted into the prepared post space. Excess material was removed with a probe before polymerization from the buccal and lingual surfaces with a light-polymerizing unit (1000 mW/cm2, Optilux 500 with Turbo Tip; Kerr Corp) at a 1-mm distance for 60 seconds each. The posts extended 3 mm beyond the sectioned root surfaces. Fine hybrid composite resin (Tetric Ceram, lot D00163; Ivoclar Vivadent) was used to develop a core around the post, which was polymerized from the buccal and lingual surfaces using a light-polymerizing unit (Optilux 500 with Turbo Tip; Kerr Corp) for 60 seconds each. The core was partially prepared and then finished in a surveyor with tapered diamond rotary cutting instruments under water cooling.

In the ZRO-POST group, size 2 (cervical diameter 1.7 mm; size 1 was not available at the time the study was conducted) cylindroconical zirconia ceramic posts (CosmoPost, lot F34596; Ivoclar Vivadent) were placed. To accommodate the posts, the root canals were enlarged from the sectioned root surfaces to a depth of 10 mm using the manufacturer's recommended drills in a slow-speed contra-angle handpiece. The 20.6-mm-long posts were placed in the post spaces and impressions were made (President Plus light body; Coltène/Whaledent AG, Altstatten, Switzerland). Casts were produced (Fujirock; GC Corp, Tokyo, Japan), and the posts were reduced to a length of 15 mm with a diamond rotary cutting instrument. Wax cores were formed around the posts (Schuler-Dental; Ulm, Germany). The zirconia ceramic posts with wax cores were embedded (Empress 2 Speed, lot D98022, F98047 and liquid lot D98023; Ivoclar Vivadent). After warming for half an hour at 850°C, liquid glass ceramic (Experimental press, lot HAT300/2366; Ivoclar Vivadent) was pressed into the lost-wax space at 920°C and 5 bar. After 60 minutes of cooling to room temperature, the posts and cores were removed and airborne-particle abraded using aluminum oxide (50 µm; Kaladent, Zürich, Switzerland) at 2 bar pressure. The posts were cleaned with steam and filled with luting resin (Variolink; Ivoclar Vivadent), and dentin bonding procedures were performed as described for group FRC-POST (Fig. 1, A).

In group GOLD-POST, 10-mm-deep preparations, impressions, and casts for size 4 (cervical diameter 1.5 mm) cylindroconical precious alloy posts (CM RCP, lot 029144; Cendres & Metaux) were made as described for ZRO-POST. The posts were reduced to a length of 15 mm and placed in post spaces prepared in the roots. Wax cores were directly formed (Schuler-Dental), and the post and core assemblies were invested (Fujivest Super; GC Corp). After warming for 50 minutes to 750°C, the cores were cast with a gold alloy (Aurofluid, lot 0052577; Metalor Dental AG, Oensingen, Switzerland). The castings were allowed to bench cool for 30 minutes, then separated from investment, airborne-particle abraded, and cleaned (Deoxybath; DeguDent, Hanau, Germany). Before insertion, posts and dentin were cleaned with 75% ethanol. Glass-ionomer cement (Ketac Cem; 3M ESPE) was applied to the posts and cores, which were subsequently inserted into the prepared post spaces (Table I). After removal of excess cement or luting resin, all cores were finished in a surveyor with tapered 25-µm grit diamond rotary cutting instruments (Intensiv No. FG 3113NR; Intensiv SA) under water cooling. This resulted in final preparations with 0.8-mm-wide shoulders and axial walls with dentin heights of 2 mm for groups ENDOCROWN, FRC-POST, ZRO-POST, and GOLD-POST. For the 3 groups with post-and-core foundations, crown preparation heights were extended 3 mm after the foundations were placed. Thus, tooth preparations had total axial wall heights of 5 mm.

For all 4 experimental groups, an individual impression (President Plus light body, Coltène/Whaledent AG) was made for each root/post-and-core assembly and dental stone dies were produced (Fujirock; GC Corp). Crowns in the form of second premolars were formed in wax (Schuler-Dental) using standardized split molds.[6] The slight differences in the cervical diameters of the premolars were manually corrected with wax (Fig. 1, B). The dies with wax crowns were invested (Empress 2 Speed, lot D98022, F98047 and liquid lot D98023, F98057;

Ivoclar Vivadent) in rings and prepared for ceramic crown pressing. After warming, lithia disilicate-based ceramic material (Experimental press, lot HAT No. /VP No: 300/2366, 200/2681, 100/2566; Ivoclar Vivadent) was pressed into the molds at 920°C and 5 bar. After cooling for about 60 minutes, the investment was removed, and the crowns were cleaned with 50-µm aluminum oxide at 2 bar pressure and adjusted to their individual dies (Fig. 1, C). Finally the ceramic crowns were glazed (Empress 2 universal glaze and stain liquid, lot 65392; Ivoclar Vivadent) at 730°C. Marginal and internal fit was evaluated (Fit Checker; GC Corp) on the tooth preparations. Occlusal ceramic thickness was 2.2 ±0. 2 mm measured with a caliper (Mod. 25502; Asa Dental SpA, Bozzano, Italy). Subsequently, the intaglio surfaces of the crowns were airborne-particle abraded with 50 µm aluminum-oxide particles and etched with 5 % hydrofluoric acid (IPS Ceramic Etching Gel; Ivoclar Vivadent) for 20 seconds. After rinsing with water, a silane (Monobond-S; Ivoclar Vivadent) was applied to the intaglio surfaces of the crowns. The solvent was allowed to evaporate for 60 seconds. The intaglio surfaces were covered with a thin film of bonding agent, which was not polymerized. A hybrid composite resin (Tetric; Ivoclar Vivadent) was applied to the intaglio crown surfaces and adapted to the walls with a ball-shaped hand instrument (MB 5; Deppeler SA, Rolle, Switzerland). In preparation for adhesive luting, all teeth were cleaned with water, toothpaste (Cleanic; Kerr Hawe), and slowly rotating nylon brushes (Kerr Hawe). All preparations were carefully refinished with hand-held 25-µm finishing diamond rotary cutting instruments (Intensiv No. FG 3113NR; Intensiv SA) with water spray at ×10 magnification (Stemi 2000; Carl Zeiss AG, Oberkochen, Germany) to remove surface contaminants from prepared dentin and to produce a fresh smear layer with minimal amount of surface removal. The dentin was conditioned with a primer (Syntac Primer; Ivoclar Vivadent) for 15 seconds, applied with gentle rubbing. After another 15 seconds, the primer was carefully dried. Next, Syntac Adhesive (Ivoclar Vivadent) was applied in similar fashion and dried after 20 seconds. The bonding agent (Heliobond; Ivoclar Vivadent) was applied, and after 40 seconds penetration time it was thinned with air and polymerized from the occlusal aspect for 60 seconds (800 mW/cm2, Optilux 500, standard light tip; Kerr Corp). The crowns with luting resin applied were placed on their preparations and brought to final positions with ultrasound (SP Tip and Piezon Master 400; EMS, Nyon, Switzerland). Excess luting resin was carefully removed with a probe. Then the luting resin was polymerized (Optilux 500 with Turbo Tip; Kerr Corp) through the crown for 120 seconds. To simulate the clinical situation, light was applied occlusally and from each axial line angle. The small amount of luting resin exposed along crown margins was polished with abrasive discs in descending grit size (Soflex Discs; 3M ESPE) with ×10 magnification.

All roots, in all groups, were covered with an air-thinned, approximately 0.3-mm-thick layer of vinyl polysiloxane (President Plus light body; Coltène/Whaledent AG) to simulate a periodontal ligament. After polymerization, the thickness of the layer was measured with a calibrated probe at the cervical, central, and apical portions of the root. Then the roots were centered on carriers (SEM carriers; Bal-Tec AG, Balzers, Liechtenstein) with a centering device (PPK, Zurich, Switzerland) and fixed in position with autopolymerizing acrylic resin (Paladur; Heraeus Kulzer GmbH, Hanau, Germany). The vertical distance between preparation finish lines and the acrylic resin level was 3 mm buccally and lingually, and 4 mm on the proximal surfaces, simulating an acceptable biological width between clinical crown margins and alveolar bone.

To quantify the changes in marginal continuity using scanning electron microscopy (SEM), teeth and restorations were cleaned with toothpaste (Signal AntiCaries; Unilever GmbH, Steinhausen, Switzerland), rotating nylon brushes (Kerr Hawe), and water. Marks were placed at each line angle of each crown, at a distance of 1 mm coronal from the finish line, with a waterproof felt tip pen (Staedtler permanent; Staedtler Mars GmbH, Nürnberg, Germany).These marks were visible on the replicas made for the SEM study and helped prevent the duplicate measurement of marginal areas. Impressions of the restored buccal, lingual, mesial, and distal tooth surfaces were made before and after thermo-mechanical loading (President Plus light body; Coltène/Whaledent AG). Replicas of these surfaces were made with epoxy resin (Stycast 1266; Emerson & Cuming, Westerlo, Belgium) and were sputter coated with gold for 1 minute (Balzers Sputter SCD 030; Bal-Tec AG). Marginal continuity along the entire length of the interfaces between tooth and luting composite resin, and between luting composite resin and restoration, were analyzed quantitatively using SEM (Amray 1810 T; Amray, Inc, Bedford, Mass) at 15 kV and at a working distance of 20 to 30 mm at ×200 original magnification. The operator was blinded as to which group the examined specimen belonged. Finish lines and crown margins were assessed for the following criteria, expressed as percentages of the total lengths examined: continuous margin (no gap, no interruption to continuity), or noncontinuous “imperfect” margins (gap due to adhesive or cohesive failure, fracture of the restorative material, or fracture of the dentin related to restoration margins). The operator was calibrated to these procedures with help of a booklet with typical SEM photographs of the latter criteria. According to internal recalibrations, measurement error for this method is less than 3%.

All specimens were loaded mechanically at the center of the occlusal surface in the computer-controlled masticator (CoCoM 2; PPK).The stress consisted of 1.2 million occlusal loads of 49 N at 1.7 Hz and simultaneous thermal stress with 3000 temperature cycles of 5°C–50°C–5°C. Specimens were then placed in a custom-made carrier with an inclination of 60 degrees (loading angle: 120 ±5 degrees) and loaded in a universal testing machine (Schenck

Trebel; TeMeCo Dubendorf, Switzerland) with a 5-mm steel sphere, centered on the center of the lingual ridge of the buccal cusps (Fig. 2). The crosshead speed of 0.5 mm/min continued until the first major load drop occurred. A 0.5-mm piece of tin foil between the steel sphere and crown allowed a more equal load distribution on the ceramic crown surface. The loads were recorded in newtons and mean values were calculated per group. After fracture, the fragments were analyzed for the failure mode: crown fracture, tooth/root fracture, and post fracture. Tooth fractures that might clinically allow for a new replacement crown were rated “reparable.” Tooth/root fractures that would require tooth extraction were rated “problematic.” These inspections were made with help of a stereomicroscope (Stemi 2000; Carl Zeiss AG). During inspection, teeth were transilluminated (Translight 5000; Volpi AG, Schlieren, Switzerland). Classification was based on a 2-examiner agreement. Cohen's kappa value for examiner agreement was 0.9.

After testing for normal distribution using the Kolmogorov-Smirnov test, marginal continuity between groups was compared statistically using 1-way analysis of variance (ANOVA). Since some range in variances existed, data was additionally analyzed with a Mann-Whitney U test, which provided the same results. Hence, the pairwise testing was reported. Initial and terminal values were compared with repeated measures ANOVA. Loads to failure were compared using 1-way ANOVA. Post hoc testing was performed with *t* tests and a Bonferroni-Dunn correction for multiple testing. The level of significance was set at 95% for all statistical testing. Confidential intervals (95% CI) were calculated to compare the probability of reparable fractures.

RESULTS

All teeth and all restorations survived thermomechanical loading in the computer-controlled masticator without visible damage. Replicas were made for analysis of marginal continuity. During water storage between replica manufacturing and static load testing, 1 crown in the ENDOCROWN grouped showed signs of debonding. This crown loosened without damage to either the restoration or tooth. Because this crown could be reseated on the tooth, the decision was made to include it in the static loading testing.

On initial replicas, 83.9 ±12.9% of margins between tooth structure and luting composite were rated continuous. A significant difference was found only between ENDOCROWN (endo-crowns, 72.4 ±15.8%) and FRC-POST (FRC posts, 94.8 ±3%, *P*<.001). After thermomechanical loading, the percentage of continuous margins decreased to 44.7 ±14.5% in ENDOCROWN, 83.9 ±4.4% in FRC-POST, 75.5 ±8.4% in ZRO-POST, and 68.6 ±19.8% in GOLD-POST groups. The decrease in marginal continuity compared to initial replicas was significant for the ENDOCROWN (*P*<.001) and FRC-POST (*P*<.001) groups. After thermomechanical loading, marginal continuity was significantly less for ENDOCROWN compared to other groups (*P*<.01).

Between the luting composite resin and lithium disilicate-reinforced all-ceramic crowns, the percentage of continuous margins was 67.2 ±12.7% before thermomechanical loading. Significant differences were found between ENDOCROWN (76.9 ±11.5) and ZRO-POST (56.1 ±3.4, *P*<.001). After thermomechanical loading, a significant decrease in marginal continuity was observed in FRC-POST, ZRO-POST, and GOLD-POST groups (*P*<.001). Marginal continuity decreased to values between 33.5 ±7.7% (ZRO-POST) and 53.9 ±16.9% (ENDOCROWN). However, differences between the groups were not significant after thermomechanical loading (Fig. 3).

Mean loads to failure in the test groups were recorded between 1092.4 ±307.8 N for FRC-POST and 1253.7 ±226.5 N for ZRO-POST. No significant differences in terms of load to failure were recorded between test groups. Comparing data of test groups with the control groups, no significant differences with the endodontically treated group, COMP, were observed Slightly higher mean loads to failure were recorded for ZRO-POST compared to the untreated premolars (UNTREATED, d*f*: 5, residual: 42, F=2.717, *P*=.32). In all test groups and in the control group COMP, approximately half of the specimens showed problematic failure characteristics, indicating that it would be clinically difficult or even impossible to restore the tooth after such a failure. Only in group UNTREATED were all fractures rated as reparable (Table II). In all groups with endodontic posts, deep root fractures involving the apical end of the post space were observed by transillumination (Fig. 4).

DISCUSSION

The data support rejection of the first null hypothesis, which stated that marginal continuity assessment values would not decrease under repetitive loading. Marginal continuity values for all-ceramic crown restorations placed on endodontically treated premolars decreased even though the material used for crown fabrication was rigid. However, the decrease was only significant for foundations with glass fiber-reinforced composite resin posts and endo-crowns. With more rigid posts, this decrease was not significant. The data do not support rejection of the second null hypothesis that loads to failure did not differ between the test groups. Coronal leakage and fractures are considered to be primary reasons for the ultimate failure of endodontically treated teeth.[12] Therefore, these critical parameters were analyzed in this study.

Marginal continuity was analyzed before and after dynamic thermomechanical loading. Subsequent static loading was used to measure loads to failure and to analyze failure patterns of the test specimens. The load was applied in an oblique direction, which is more detrimental than an axial load.[20]

Although much effort was made to simulate the clinical service of endodontically treated premolars, a study limitation is that many factors that might influence restoration longevity, such as nutrition, bruxism, and other individual parafunctional habits, were not simulated. Another limitation is that the results are obtained with test specimens made using a single ceramic crown material, which renders generalizations derived from the results difficult.

To evaluate the influence of the crown material on marginal continuity and fracture behavior, the study was designed to be similar to a recently published study by Stricker and Göhring.[6] Therefore, all preparations, post and core materials, and foundation fabrication procedures were identical. In contrast to this previous study, in which fine-hybrid composite resin crowns were used (Targis; Ivoclar Vivadent), crowns in the present study were made of an experimental pressable high-strength ceramic. This ceramic was selected because it was described as a hydrofluoric acid-etchable ceramic, compatible with established adhesive luting procedures. Moreover, it has a high flexural strength of 400 MPa when subjected to a 3-point bending test, as purported by the manufacturer. Based on this strength, the material was rated suitable for single tooth copings and fixed partial denture frameworks in the anterior and premolar region.

To achieve maximum standardization, the same split molds used to form composite resin crowns in the previous study[6] were used in the present study to mold wax crowns. Therefore, crown sizes and dimensions were similar in all groups, in both studies. Therefore, the results from the 2 studies could be compared. In both studies, the poorest marginal continuity between tooth structure and luting composite resin was measured for endo-crowns without posts after thermomechanical loading. This might indicate a higher risk for clinical failures with endo-crowns resulting from bacterial penetration, secondary caries, and loss of retention, independent of the materials used.[8] This is in agreement with clinical data regarding endo-crowns placed on premolars.[5] Better marginal continuity values were obtained after thermomechanical loading when endodontic posts were used in the restorations. This observation is in agreement with the findings reported by Stricker and Göhring[6] in their investigation of composite resin crowns. No significant differences were detected between groups, irrespective of the post and core materials used. Again, the greatest loss of marginal continuity was observed with the less rigid FRC posts when data before and after thermomechanical loading were compared. This result may support data from a finite element analysis study, in which high stress was measured cervically at the tooth-to-restoration interface in teeth restored with FRC posts.[16] However, in the present study, this decrease in marginal continuity of all-ceramic crowns resulted in measurements of more than 80% continuous margins. For comparison, marginal continuity of composite resin crowns decreased from approximately 95% continuous margins initially to 65% after thermomechanical loading.[6] In this situation, in which tooth preparations and crown foundations were identical, the stronger, more rigid all-ceramic crown material seems to have positively affected marginal continuity values. This crown material combined with the ferrule effect provided by the crown design might also explain why no significant differences could be detected in marginal continuity between post-and-core restored groups after thermomechanical loading.

Regarding susceptibility for secondary caries, the interface between the luting composite resin and crown may not be as critical as the tooth structure-luting resin interface. However, if a gap occurs at this interface, discoloration may lead to an unsightly delineation of the crown margin.[7] Initial values of 70%, which decreased after thermomechanical loading to values of approximately 40%, were unexpected. Therefore, a second researcher, who was again blinded to group assignment of the specimens, repeated all measurements. Both sets of measurements were identical. It might be that the micromechanical retention achievable by etching the intaglio crown surfaces with hydrofluoric acid was not sufficient for creating an adequate bond between composite resin and the lithia disilicate-based ceramic. Whereas marginal continuity is a good indicator of effective resin bonding to cervical root dentin, the ideal pretreatment for adhesive resin bonding to lithia disilicate-based ceramic surfaces should be evaluated and optimized in further studies.

When loaded to failure, endodontically treated teeth with lithia disilicate-based ceramic crowns failed at mean values of approximately 1100 N. This was high compared to other published load-to-failure values for restored teeth of between approximately 200 N and 900 N.[14,21] Values recorded in the present study were those for catastrophic failure. First minor load drops and first crack sounds were recorded at lower values, between 212 to 944 N for some specimens before catastrophic failure. However, in about one third of the specimens, the first crack sound or load drop was identical with catastrophic failure. There was no characteristic pattern of first crack signs and the distribution was uneven. Therefore, the decision was made to present only the data for catastrophic failure.

With these comparably high loads to failure, lithia disilicate-based ceramic crowns seemed to be superior to composite resin crowns, which failed at mean values between 450 N and 670 N. In contrast to the composite resin crown study,[6] in which no deep root fractures were observed, such fractures were detected in all groups of the current study. One tooth with an endocrown, 3 teeth in group GOLD-POST, and 4 teeth in each of the FRC-POST and ZRO-POST groups developed deep root fractures. These fractures directly involved the apical end of the post space. Load transfers from rigid ceramic crowns via a rigid post to the post space walls results in high stresses at the post-to-root dentin interface.[16] This resulted in deep root fractures such as those observed in other studies.[11-13] These fractures occurred independent of materials used for post fabrication. Although no deep root fractures were observed with composite resin crowns, and most of these specimens failed from fractures of the composite resin crown material, the same number of specimens failed with problematic fracture modes in both studies. The failure of the composite resin crowns was usually accompanied by chiplike fractures of the cervical dentin, 3 to 5 mm below the original finish line.[6] Therefore, the fracture of composite resin crowns under lower loads did not result in reparable failures. Consequently, this type of crown could not be recommended.[6]

The lack of an advantage for FRC posts with regard to load transfer in the present study is in contrast to a previous finite element study.[16] It is also in contrast to a literature review of in vitro studies, where FRC posts frequently showed more favorable failure modes compared with metal posts.[19] However, another study showed that FRC posts can produce failures similar to those reported for rigid ceramic posts.[14] In a different literature review on performance of endodontic posts, it was concluded that great differences in failure rates for different post systems were not obvious.[18] This is in agreement with the results from the present study. Factors, such as the amount of remaining tooth structure, ferrule effect of the crown, and material composition of the crown, as well as magnitude and direction of functional loads, seem to have a greater influence on survival than the specific post system used.[18]

As shown in the current study, specimens without endodontic posts displayed poor marginal continuity without any advantages with regard to failure behavior. Thus, the idea that risks related to post space preparation in premolars could be avoided by using currently available adhesive bonding materials should be reconsidered. If a post space preparation cannot be completely avoided, it might be beneficial to have further in vitro studies focused on using short adhesively bonded posts. This approach might decrease the risk of operational errors in post space preparations and might overcome application problems that accompany the use of contemporary adhesive systems in deep post space preparations.[3] Although FRC posts in the present study were not superior to cast posts and cores, according to marginal continuity and failure behavior, they were, nevertheless, not inferior. Additionally, FRC posts have displayed some advantages in clinical practice. They involve less clinical and laboratory time and expense, and the crown foundations can be completed in a single patient visit. This approach also avoids or minimizes the exposure of post spaces to bacterial contamination during provisional care and delays related to laboratory procedures. Also, FRC posts are easily removed in the event that endodontic retreatment becomes necessary.[3]

The results from this in vitro study seem to present FRC posts as a comparable alternative to the other post materials investigated in this project. Although in vitro studies have known shortcomings and limitations, the standardized conditions of this study allow some conclusions to be drawn for the restoration of endodontically treated mandibular premolars with 2 mm of sound tooth structure remaining occlusal to complete crown finish lines.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. The restoration of endodontically treated mandibular premolars with endo-crowns cannot be recommended over treatment using post-and-core foundations when lithia disilicate-based ceramic crowns are indicated.
2. Based on marginal continuity assessments, teeth restored with post-and-core foundations and ceramic crowns demonstrated significantly greater resistance to thermal and dynamic loading stresses compared to teeth restored with ceramic crowns of the endo-crown design. The greater stress resistance observed was not accompanied by significant negative effects on fracture resistance and fracture mode.

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Table I. Study groups

Group	ET[*]	Ferrule	Post	Cement	Core
UNTREATED	No	No	No	No	No
COMP	Yes	No	No	No	No
ENDOCROWN	Yes	Yes	No	No	No
FRC-POST	Yes	Yes	FRC[+]	Variolink (Ivoclar Vicadent)	Resin [#]
ZRO-POST	Yes	Yes	ZrO[‡]	Variolink	Ceramic
GOLD-POST	Yes	Yes	Gold	Ketac Cem (3M ESPE)	Gold

[*] ET: endodontically treated, [+] FRC: glass fiber-reinforced composite, [‡] ZrO: zirconia ceramic,

[#] Resin: composite resin core

Table II. Loads to failure and failure characteristics (n=8)

	Load to Failure (N)				Failure Characteristics		
	Mean (SD)	Significance	Minimum	Maximum	Problematic	Reparable	
Group					n (%)	n (%)	95% CI[*]
UNTREATED	849.0 (94.0)	A	713	1037	0 (0)	8 (100)	63 – 100
COMP	1031.9 (266.7)	AB	500	1433	3 (37)	5 (63)	25 – 92
ENDOCROWN	1107.3 (217.1)	AB	700	1367	4 (50)	4 (50)	16 – 84
FRC-POST	1092.4 (307.8)	AB	528	1420	4 (50)	4 (50)	16 – 84
ZRO-POST	1253.7 (226.5)	B	792	1488	5 (63)	3 (37)	9 – 76
GOLD-POST	1101.2 (182.9)	AB	896	1404	3 (37)	5 (63)	25 – 92

Groups with same uppercase letters did not significantly differ statistically (*P*>.05).

[*] 95% confidence interval for probability of reparable fracture

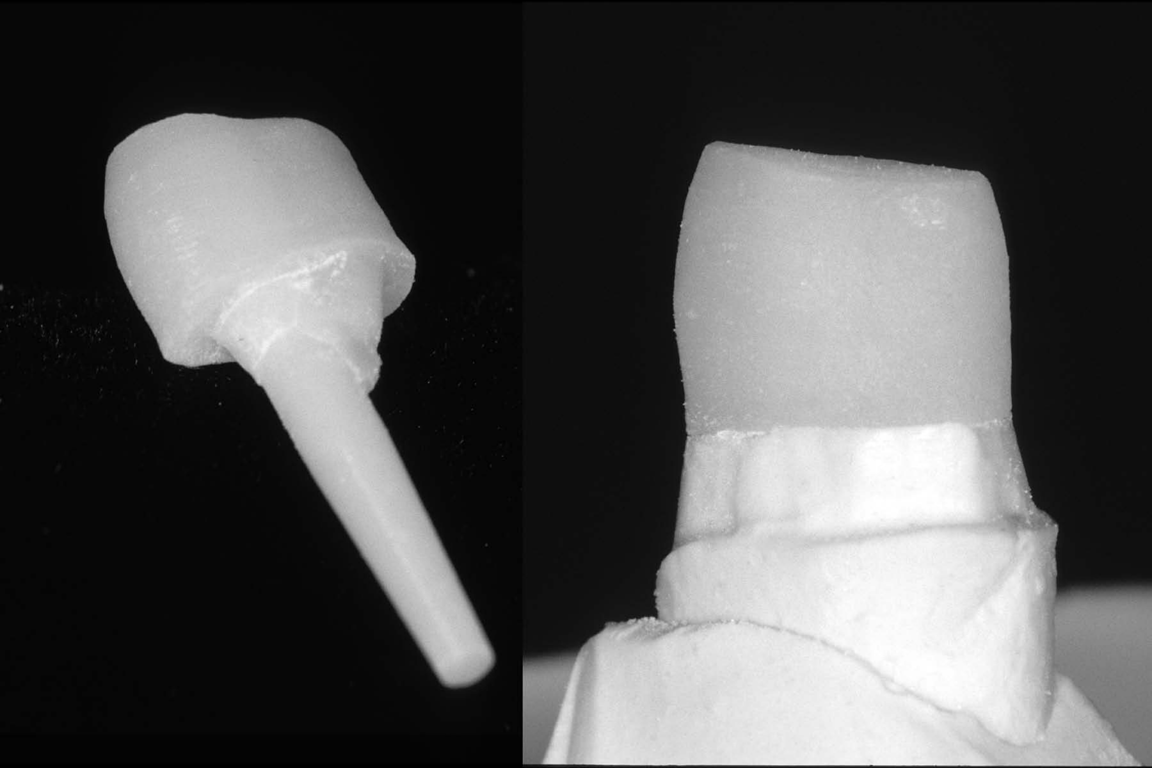
LEGENDS

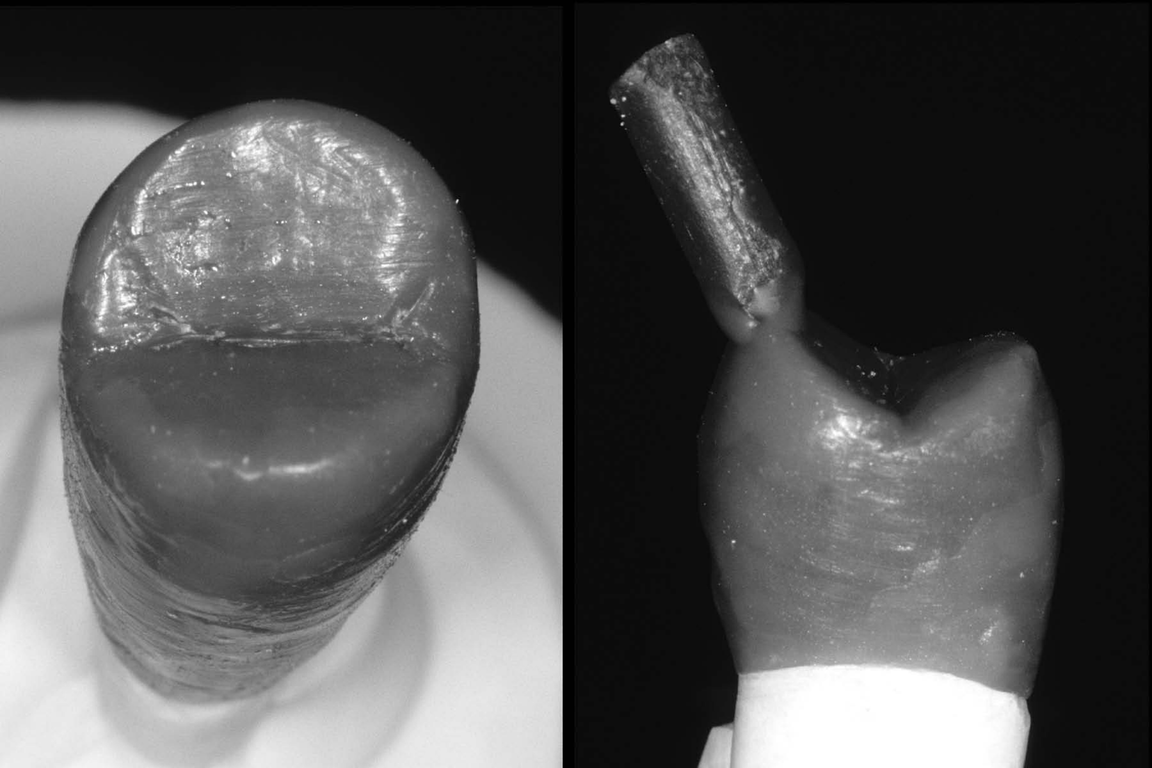
Fig. 1. A, Zirconia ceramic endodontic post with heat-pressed ceramic core. All preparations had vertical height of 5 mm (2 mm of coronal dentin, 3 mm of core height). B, Standardized wax crown pattern. C, Heat-pressed lithia disilicate-based ceramic crowns.

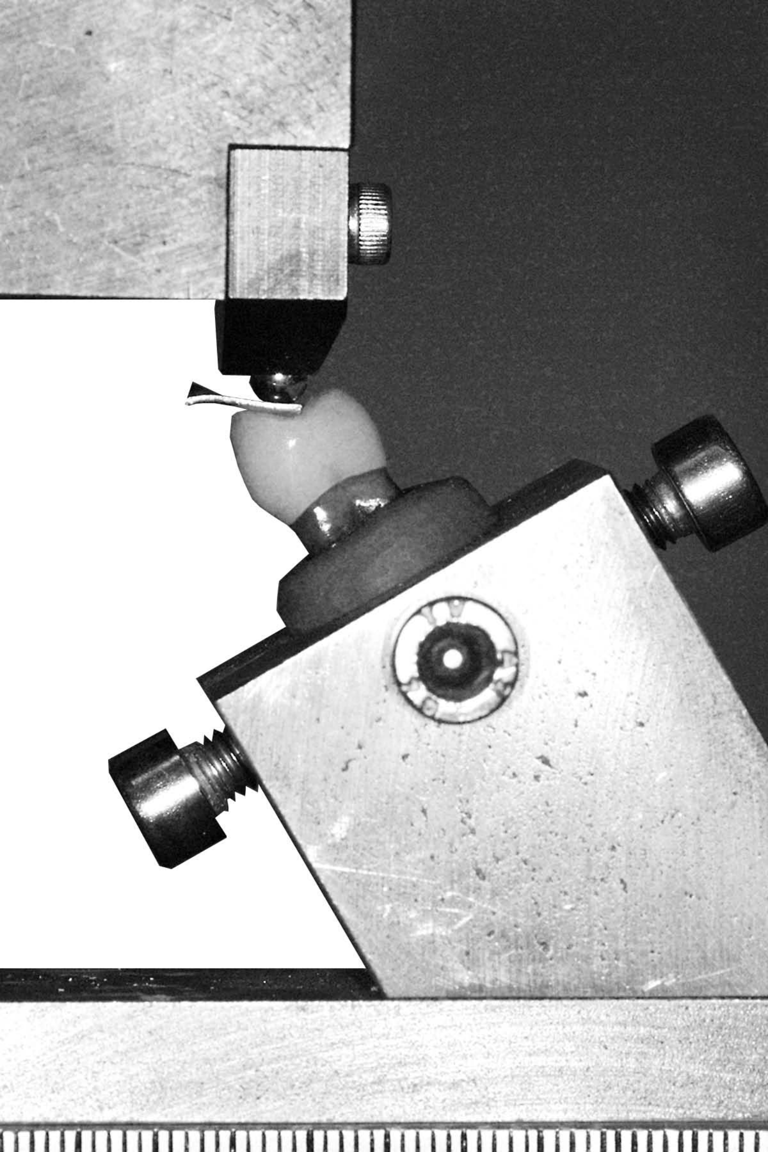
Fig. 2. For static load test, steel sphere was centered on lingual ridge of buccal cusp. Tin foil was placed between sphere and ceramic surface.

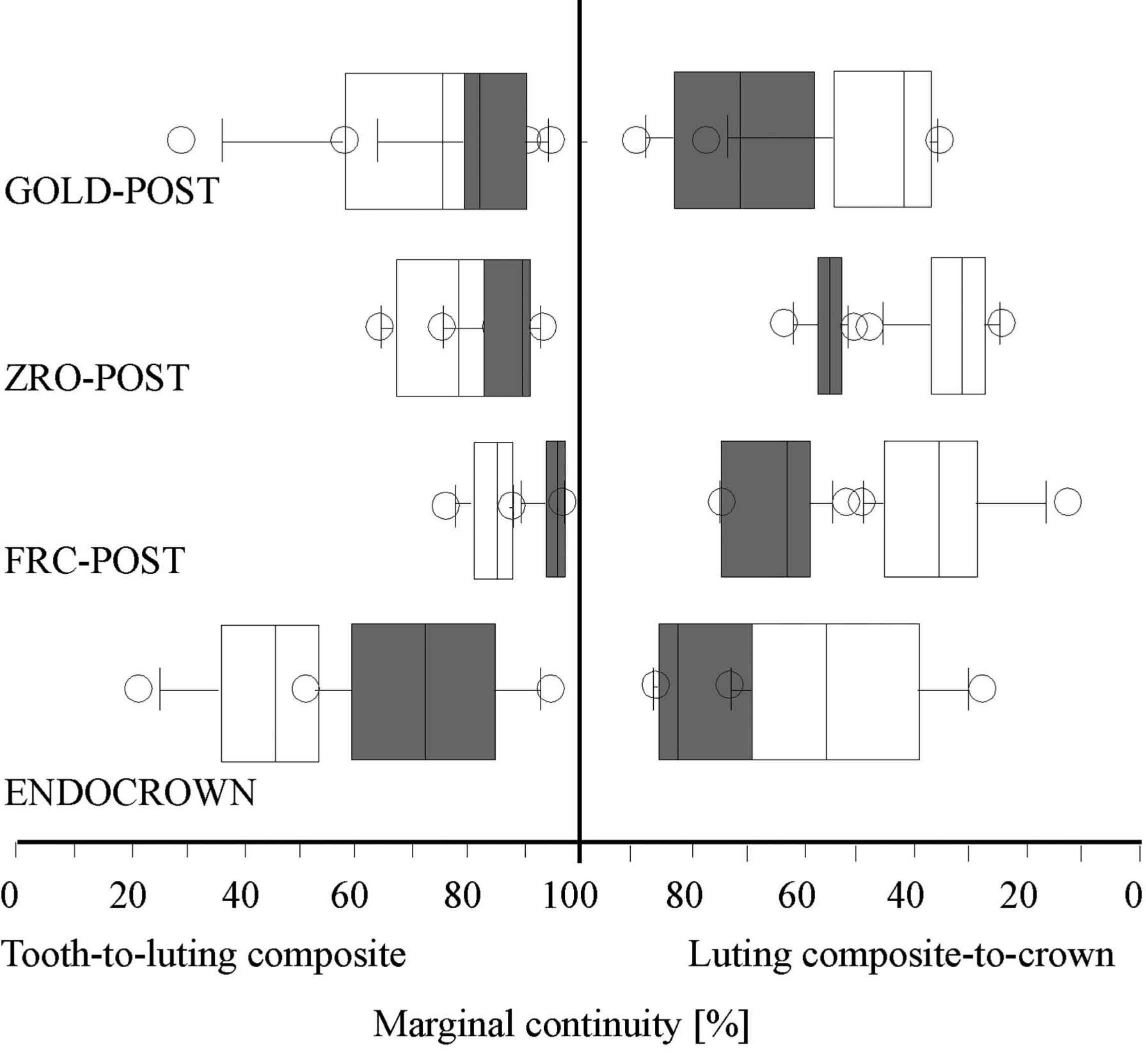
Fig. 3. Marginal continuity was analyzed at tooth-to-luting resin and luting resin-to-crown interfaces, before (gray box plots with median, 25th and 75th percentiles; circles: values above 90th and below 10th percentile) and after (white box plots) cyclic thermomechanical loading.

Fig. 4. Fracture modes observed after static loading to failure. Lines indicate complete fractures with separation of fragments, and arrows indicate fracture lines without separation. Numbers provide count of respective fractures observed per group. Black numbers and lines indicate noncritical fractures; red numbers and lines indicate critical fractures, meaning that tooth would be difficult or impossible to restore following fracture of this type. One specimen each in groups UNTREATED, ZRO-POST, and GOLD-POST, and 2 in group FRC-POST, did not have visible tooth fractures after crown failure, and were rated as reparable fractures.








GOLD-POST
ZRO-POST
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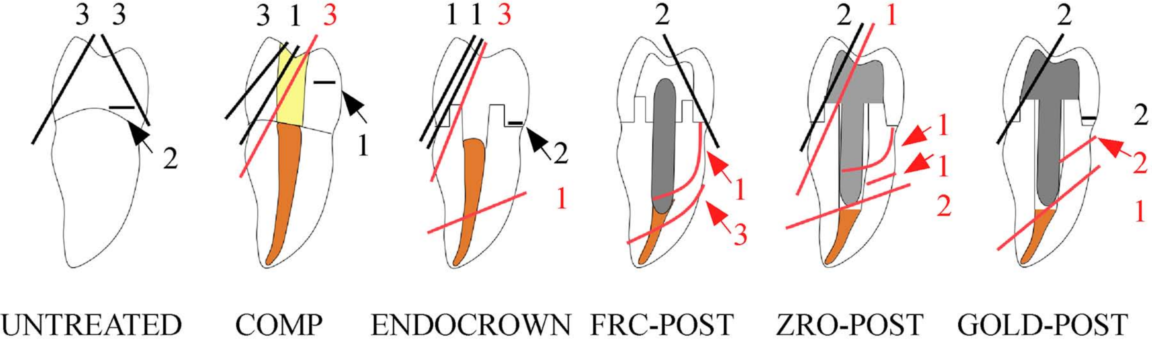
Tooth-to-luting composite
Luting composite-to-crown
Marginal continuity [%]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UNTREATED
COMP
ENDOCROWN
FRC-POST
ZRO-POST
GOLD-POST

Table 1. Groups

Group	RCT[1]	Ferrule	Post	Cement	Core
Untreated	no	no	no	no	no
COMP	Yes	no	no	no	no
ENDOCROWN	Yes	Yes	no	Variolink	no
FRC-POST	Yes	Yes	FRC[2]	Variolink	Composite
ZRO-POST	Yes	Yes	ZrO[3]	Variolink	Ceramic
GOLD-POST	Yes	Yes	Gold	Ketac Cem	Gold

[1] RCT: root canal treated, [2] FRC: fiber-reinforced composite, [3] ZrO: zirconium oxide

Table 2. Loads to failure and failure characteristics

		Load to Failure (N)				Failure characteristics		
		Mean ± SD	Significance[1]	Minimum	Maximum	Problematic	Reparable	
Group	n					n [%]		95% CI[2]
Untreated	8	849.0 ± 94.0	A	713	1037	0 [0]	8 [100]	63 – 100
COMP	8	1031.9 ± 266.7	AB	500	1433	3 [37]	5 [63]	25 – 92
ENDOCROWN	8	1107.3 ± 217.1	AB	700	1367	4 [50]	4 [50]	16 – 84
FRC-POST	8	1092.4 ± 307.8	AB	528	1420	4 [50]	4 [50]	16 – 84
ZRO-POST	8	1253.7 ± 226.5	B	792	1488	5 [63]	3 [37]	9 – 76
GOLD-POST	8	1101.2 ± 182.9	AB	896	1404	3 [37]	5 [63]	25 – 92

Groups with the same letters did not differ significantly statistically ($P<.05$).

[1] One-way ANOVA with correction for multiple testing (Bonferroni/Dunn).

[2] 95% Confidence interval for the probability of a reparable fracture